4.0 CONTAINMENT

4.1 Containment Boundary

This section identifies the containment boundary considered for the package.

4.1.1 Containment Vessel

Two independent levels of containment are established within the RH-TRU 72-B Cask. In general, each containment vessel is constructed primarily of ASTM A-240, Type 304, austenitic stainless steel. The exceptions are so noted in the following detailed descriptions.

4.1.1.1 Inner Vessel

The Inner Vessel (IV) containment boundary is identified as the 32.0-inch outside diameter by 3/8-inch wall thickness shell, the 1 ½-inch thick bottom end plate, the closure-end forging, and the 6 ½-inch thick IV lid, complete with the lid middle O-ring seal, the gas sampling port closure bolt with closure bolt outer O-ring seal, and the backfill port closure bolt with closure bolt O-ring seal. The sealing surfaces are machined to a maximum of 125 RMS micro-finish for sealing reliability.

With reference to the Packaging General Arrangement Drawing in Appendix 1.3.2, the inner vessel containment boundary consists of the following components:

1. A 1 ½-inch thick, Type A-304 stainless steel bottom forging

2. A 3/8-inch thick, 32-inch outside diameter, Type A-304 stainless steel shell, with a full length, full penetration seam weld

3. A full-penetration girth weld joining the shell to the bottom forging

4. An upper end (lid end), Type A-304 stainless steel ring forging

5. A full-penetration girth weld joining the upper end ring forging to the shell

6. A 6 ½-inch thick, Type A-304 stainless steel lid

7. A butyl containment O-ring which forms the seal between the upper end forging and the lid (the containment O-ring is the middle of the three inner vessel closure seals)

8. A Type A-304 or Type A-316 stainless steel gas sampling port insert, containing a Nitronics 60 closure bolt with two butyl O-ring seals. The upper O-ring seal is the containment seal.

9. A ¼-inch bevel weld which seals the gas sampling port insert to the lid

10. A Type A-304 or Type A-316 stainless steel backfill port insert, containing a Nitronics 60 closure bolt with butyl O-ring seal

11. A ¼-inch bevel weld which seals the backfill port insert to the lid

12. A Type A-304 or A-316 stainless steel test port insert

13. A ¼-inch bevel weld which seals the test port insert to the lid

The maximum inside diameter of the inner vessel is 31 ¼ inches. Two (2) intermediate support rings are located inside the inner vessel for payload canister support. Including the support rings and upper forging, a 26 ½-inch minimum diameter by 121 ½-inch long cavity is provided within the inner vessel for the packaging payload.

The specific inner vessel containment components are illustrated in Figure 4.1.1.1-1.

The non-Type 304 stainless steel components utilized in the containment boundary are the butyl O-ring seals (containment seals for the gas sampling port closure bolt, backfill port closure bolt, and the lid), and the Nitronics 60 gas sampling port and backfill port closure bolts.

4.1.1.2 Outer Cask

The Outer Cask (OC) containment boundary is identified as the 32 3/8-inch inside diameter by 1-inch thick inner shell, the 5-inch thick cask bottom end plate, the closure-end forging, and the 6-inch thick OC lid, complete with the lid inner O-ring seal, and the gas sampling port closure bolt with closure bolt O-ring seal. The sealing surfaces are machined to a maximum of 125 RMS micro-finish for sealing reliability.

With reference to the Packaging General Arrangement Drawing in Appendix 1.3.2, the outer cask containment boundary consists of the following components:

1. A 5-inch thick, Type A-304 stainless steel bottom forging

2. A 1-inch thick, 34 3/8-inch outside diameter, Type A-304 stainless steel inner shell, with a full length, full penetration seam weld

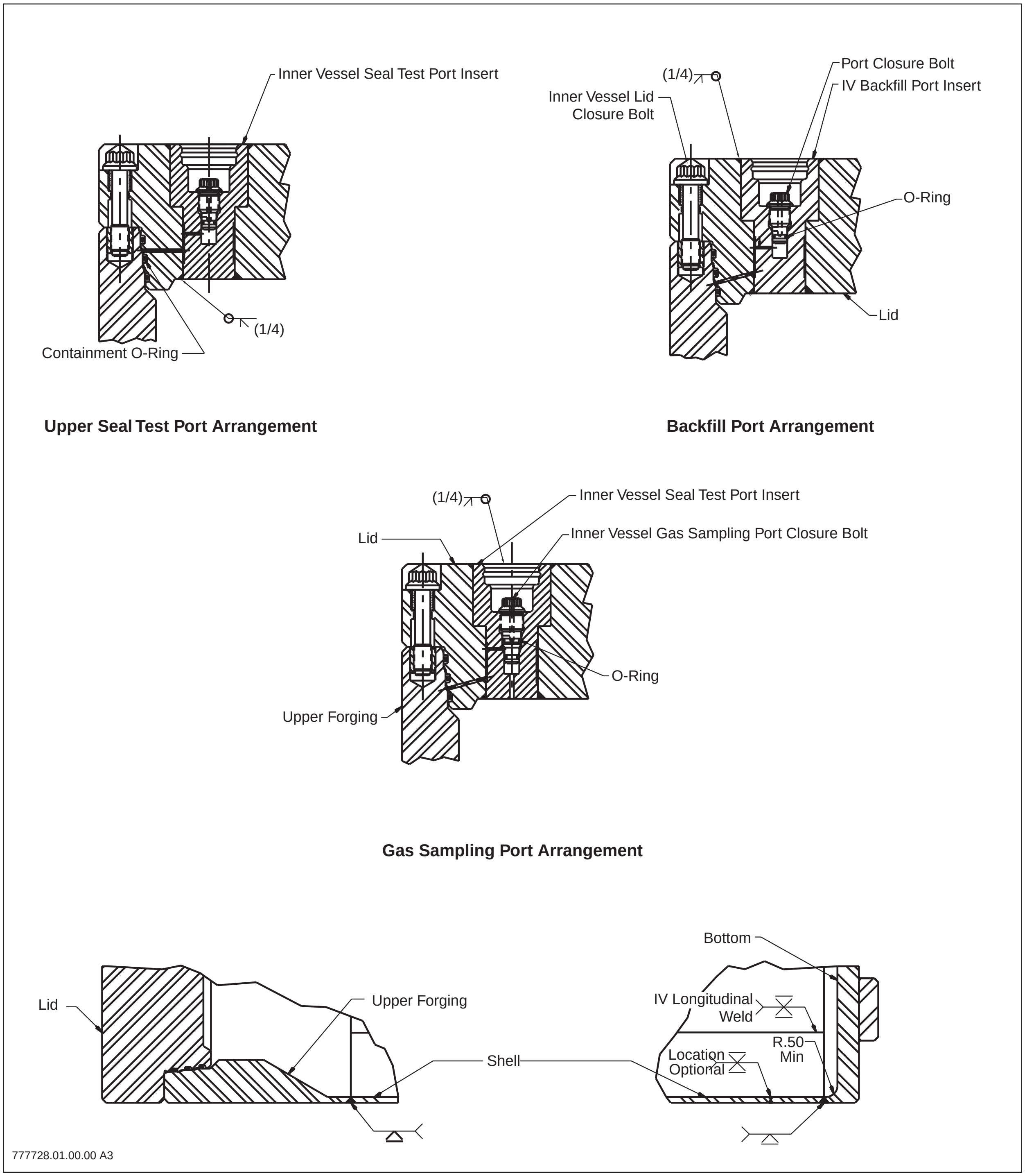

Figure 4.1.1.1-1

Inner Vessel Containment Components

3. A full-penetration girth weld joining the inner shell to the bottom forging

4. An upper end (lid end), Type A-304 stainless steel ring forging

5. A full-penetration girth weld joining the upper end ring forging to the inner shell

6. A 6-inch thick, Type A-304 stainless steel lid

7. A butyl containment O-ring which forms the seal between the upper end forging and the lid (the containment O-ring is the innermost of the two Outer Vessel closure seals)

8. A Type A-304 or Type A-316 stainless steel gas sampling port insert, containing a Nitronics 60 closure bolt with butyl O-ring seal

9. A ¼-inch bevel weld which seals the gas sampling port insert to the lid

10. A Type A-304 or A-316 stainless steel test port insert

11. A ¼-inch bevel weld which seals the test port insert to the lid

A 32 3/8-inch diameter by 130 3/4-inch long cavity is provided within the outer cask for the inner vessel.

The specific outer cask containment components are illustrated in Figure 4.1.1.2-1.

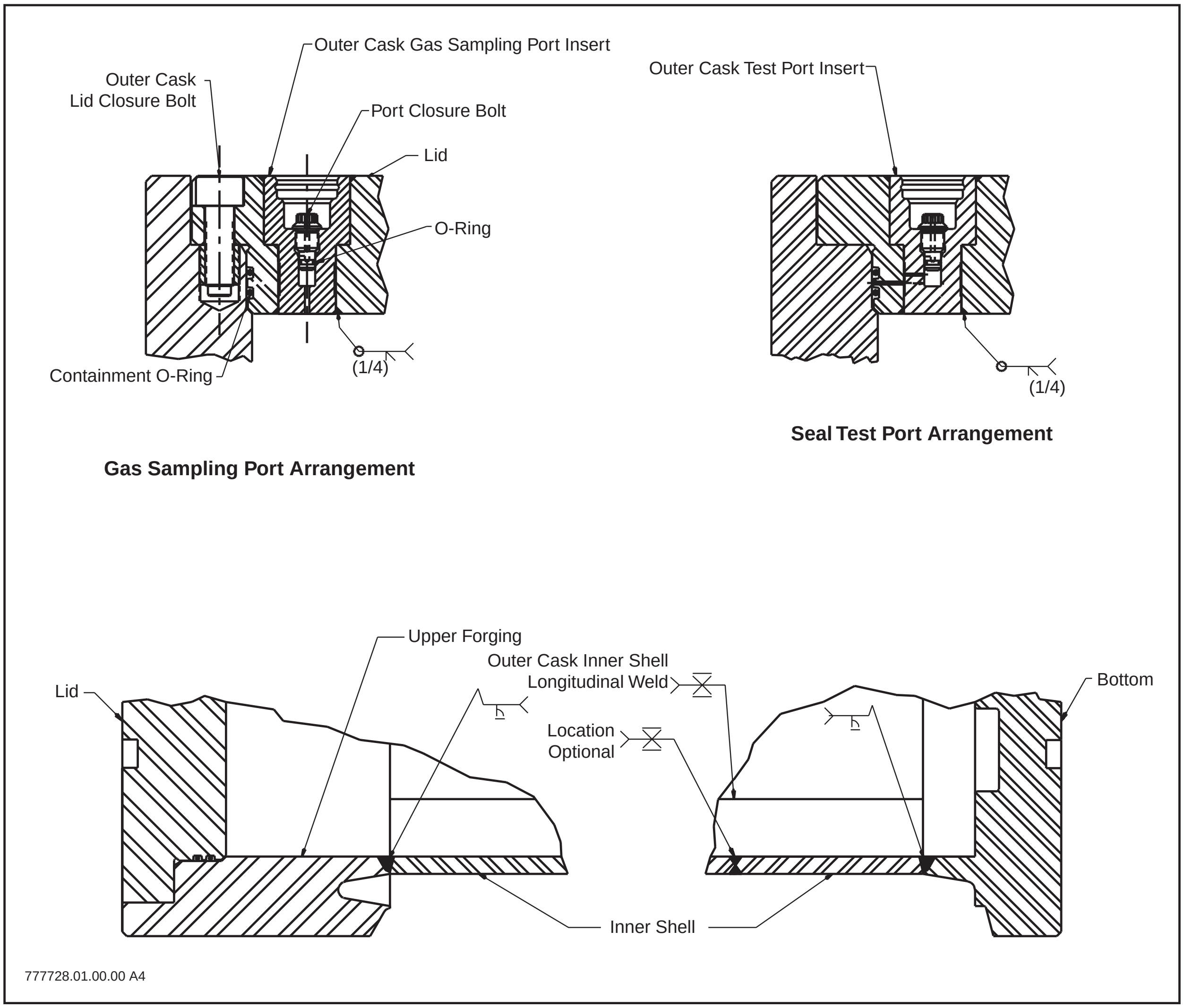

Figure 4.1.1.2-1

Outer Cask Containment Components

The non-Type 304 stainless steel components utilized in the containment boundary are the butyl O-ring seals (containment seals for the gas sampling port closure bolt and the lid), and the Nitronics 60 gas sampling port closure bolt.

Inadvertent opening of the cask closures cannot occur for the RH-TRU 72-B Cask. Following installation of the cask payload, the IV lid is secured via eight (8), 7/8 - 9 UNC bolts. The OC closure lid is then secured via eighteen (18), 1-¼ - 7 UNC bolts, thus eliminating access to the IV closure. The closure-end impact limiter is attached using six (6), 1-¼ - 7 UNC bolts. When installed, the impact limiter eliminates access to the OC closure. With this double containment closure and the presence of the impact limiter, inadvertent opening of the cask cannot occur.

4.1.2 Containment Penetrations

The only containment penetrations into each of the two containment vessels, the IV and OC, are the test and gas sampling ports, and the lids themselves. In addition, the IV has a backfill port. The detail of each penetrations is show in the Package General Arrangement Drawings in Appendix 1.3.2. Each penetration is designed to maintain a leakage rate not to exceed 1×10^{-7} standard cubic centimeters per second (scc/sec), air, so defined as "leaktight" per ANSI N14.5-1997 (Reference 4.4.1.1), for all normal and hypothetical accident conditions. All IV penetrations are covered by the OC lid, and all OC penetrations are covered by the impact limiters. These coverings along with tamper indicating lock wires assure that unauthorized operation is precluded.

4.1.3 Seals and Welds

4.1.3.1 Seals

Seals affecting containment are described above. A summary of seal testing prior to first use, during routine maintenance, and upon assembly for transportation is as follows.

4.1.3.1.1 Fabrication Leakage Rate Test

During fabrication, following the pressure testing per Section 8.1.2.2, both the OC and IV shall be individually tested per the Fabrication Leakage Rate Test, delineated in Section 8.1.3. This test verifies the containment integrity of the RH-TRU 72-B Cask to a leakage rate not to exceed 1 x 10^{-7} scc/sec, air.

4.1.3.1.2 Maintenance Leakage Rate Test

The Maintenance Leakage Rate Test delineated in Section 8.2.2 shall be performed on the cask annually. Additionally, upon repair of an O-ring sealing surface, and/or replacement of a containment O-ring seal, a gas sampling port closure bolt, or a backfill port closure bolt (IV only), the appropriate section of the Maintenance Leakage Rate Test delineated in Section 8.2.2 shall be performed to verify that the repaired or replaced component is maintained to be "leaktight" per ANSI N14.5-1997, Reference 4.4.1.1. This test verifies the sealing integrity of the RH-TRU 72-B Cask to a leakage rate not to exceed 1 x 10^{-7} scc/sec, air.

4.1.3.1.3 Preshipment Leakage Rate Test

Prior to shipment of the loaded RH-TRU 72-B Cask, both the OC and IV shall be individually leakage rate tested per the Preshipment Leakage Rate Test, delineated in Appendix 7.4.2.

As an option, the Maintenance Leakage Rate Test, delineated in Section 8.2.2, may be performed in lieu of the Preshipment Leakage Rate Test.

4.1.3.2 Welds

All containment vessel welds are full penetration welds which have been radiographic or ultrasonic test inspected to ensure structural integrity. All containment boundary welds are confirmed to be leaktight per the Fabrication Leakage Rate Test in Section 8.1.3.

4.1.4 Closure

4.1.4.1 Outer Cask (OC) Closure

Closure of the Outer Cask is effected by eighteen (18), ASTM A-320, Grade L43, 1-¼ - 7 UNC, bolts tightened to 600-700 ft-lbs.

4.1.4.1 Inner Vessel (IV) Closure

Closure of the Inner Vessel is effected by the eight (8), ASTM A-320, Grade L43, 7/8 - 9 UNC, bolts tightened to 100-200 ft-lbs.

4.2 Requirements for Normal Conditions of Transport

The results of the structural and thermal analyses performed in Sections 2.0 and 3.0, respectively, verify that there will be no release of radioactive materials per the "leaktight" criterion of ANSI N14.5-1997 (Reference 4.4.1.1) under any of the normal conditions of transport.

4.2.1 Containment of Radioactive Material

The "leaktight" containment criteria of ANSI N14.5-1997 (Reference 4.4.1.1) specified for the structure and seals of the RH-TRU 72-B Cask ensures that the requirements of 10 CFR §71.51 (Reference 4.4.1.2) are satisfied under normal conditions of transport.

4.2.2 Pressurization of Containment Vessel

The design pressure of both the RH-TRU 72-B Packaging Inner Vessel and Outer Cask is 150 psig. Results from the analyses presented in Section 3.4.4 verify that any increase in pressure, due to an increase in temperature of the initial cask gas atmosphere or due to the water vapor pressure from the water assumed present in the vessel cavity, will be equal to or less than 150 psig in both the IV and OC vessels. A pressure increase to 150 psig in either containment vessel will not reduce the effectiveness of the RH-TRU 72-B Cask to maintain containment integrity per Section 4.2.1.

4.2.3 Containment Criterion

The IV and OC shall be leakage rate tested as described in Sections 8.1.3, 8.2.2, and 4.1.3.1.3 to demonstrate the containment criterion of Section 4.2.1, at the completion of fabrication, for maintenance, or for assembly verification prior to transport, respectively.

4.3 Containment Requirements for the Hypothetical Accident Conditions

The results of the structural and thermal analyses performed in Sections 2.0 and 3.0, respectively, verify that there will be no release of radioactive material per the "leaktight" criterion of ANSI N14.5-1997 (Reference 4.4.1.1) under any of the hypothetical accident conditions of transport.

The 72-B cask containment O-rings are fabricated from Rainier Rubber Butyl Compound RR-0405-70 (ASTM D2000 M3AA 710, B13, F17, Z TRACER ELEMENT). This compound was extensively tested under a wide range of compression and temperature conditions during the development program for the TRUPACT-II packaging (NRC Certificate of Compliance No. 71-9218). The worst service condition for the O-rings was found to be at the minimum temperature of -20°F. At this low temperature, the loss of seal material resiliency is greatest. Consequently, sudden offset of the lid could result in loss of leak-tight sealing capability. The TRUPACT-II test conditions included imposing nominal seal compression (centered lid condition) at the minimum service temperature, followed immediately by minimum compression (simulating full lid offset). Under these test conditions, it was determined that a minimum residual compression of approximately 15% was required to maintain consistent “leaktight” sealing capability for the butyl seal material. Additional testing of Rainier Rubber Butyl Compound RR-0405-70 was performed during development of the RTG Package (DOE C of C No. 71-9904). That testing demonstrated that compressions as low as 10% will still result in a “leaktight” seal at both hot (at and above 350°F) and cold (-40°F) conditions. The RTG seal test results are documented in Appendix 2.10.6 of Reference 4.4.1.3.

The Inner Vessel closure seal configuration consists of three O-ring bore seals, each located on a different diameter of the IV lid. Refer to Drawing X-106-500-SNP, Sheet 5 in Appendix 1.3.2 for details. The middle O-ring is defined as the containment boundary (the inner O-ring retains the test gas for helium leak-checking, while the outer O-ring provides an annulus in which to establish a vacuum for leak-checking). In order to determine the minimum compression that may occur on the IV containment O-ring, the largest tolerance stackup on the lid, flange and O-ring groove dimensions will be utilized. The smallest radial gap occurs at the location of the upper O-ring. The maximum upper flange inside diameter at this location is 28.006 inches. The minimum IV lid diameter at the same location is 27.990 - .005 = 27.985 inches. Therefore, the minimum possible radial clearance for a centered lid is (28.006 - 27.985)/2 = 0.0105 inch. For a lid fully shifted off-center, this clearance will double on one side of the flange, for a maximum clearance of 2 x 0.0105 = 0.021 inch between lid and flange.

The minimum containment O-ring groove diameter is 27.368 inches. The maximum lid diameter at this point is 27.73 + 0.06 = 27.79, for a maximum O-ring groove depth of (27.79 - 27.368)/2 = 0.211 inch. The maximum possible clearance between the bottom of the O-ring groove and the adjacent sealing surface on the upper flange is thus 0.021 + 0.211 = 0.232 inch. The minimum IV O-ring cross-sectional diameter is 0.275 - 0.003 = 0.272 inch. The minimum possible residual O-ring compression is thus [(0.272 - 0.232)/0.272] x 100% = 15%. Given the O-ring seal test results, the current IV containment seal design is adequate to ensure that a minimum residual O-ring compression will be maintained under worst-case tolerance stackup and lid offset conditions.

The Outer Vessel closure seal configuration consists of two O-ring bore seals, both at the same diameter on the OV lid. Refer to Drawing X-106-500-SNP, Sheet 4 in Appendix 1.3.2 for details. The inner O-ring is defined as the containment seal (the outer O-ring provides a vacuum annulus for helium leak checking, where the test gas is contained in the void space between the IV and OV). The OV upper flange diameter at the containment O-ring location is 32.893 ± 0.003 inches.

The maximum possible OC lid offset condition will occur when the lid O.D. is at its minimum value (32.861 inches), and the flange I.D. is maximum (32.896 inches). In this case the maximum O-ring groove depth will be

(32.861 – 32.265)/2 = 0.298 inch. The maximum lid offset will be 32.896 – 32.861 = 0.035 inch. The maximum distance between the bottom of the O-ring groove and the flange sealing surface will thus be 0.298 + 0.035 = 0.333 inch. Minimum O-ring compression will therefore be (0.387 - 0.333)/ 0.387 x 100% = 14% residual O-ring squeeze, which is above the required minimum value of 10%, as determined by seal test results.

4.3.1 Fission Gas Products

There are no fission gas products in the RH-TRU 72-B Cask.

4.3.2 Containment of Radioactive Material

The "leaktight" containment criteria of ANSI N14.5-1997 (Reference 4.4.1.1) specified for the structure and seals of the RH-TRU 72-B Cask ensures that the requirements of 10 CFR §71.51 (Reference 4.4.1.2) are satisfied under the hypothetical accident conditions. The “leaktight” containment design will be verified by the fabrication verification leak checks of the initial production cask. Refer to Section 8.1.3 for details.

4.3.3 Containment Criterion

The RH-TRU 72-B Cask has been designed, constructed, and verified by leakage rate testing, to meet the "leaktight" criteria established in ANSI N14.5-1997 (Reference 4.4.1.1).

The results of the structural and thermal analyses performed in Sections 2.0 and 3.0, respectively, verify that the RH-TRU 72-B Cask will meet the "leaktight" criterion of ANSI N14.5-1997 (Reference 4.4.1.1) under any of the hypothetical accident conditions of transport. Refer specifically to Section 2.7.6. These results verify that structurally, there is no compromise of the containment boundary in accident conditions. They verify thermally, that seal surface temperatures remain low enough to prevent deformation of the sealing materials, such that the "leaktight" criterion is maintained.

The only damage arising from normal conditions of transport involves minor deformations to the impact limiter(s), which have no effect on packaging containment ability. The analyses presented in Sections 2.7.1 through 2.7.5 of Chapter 2.0 show that the accident test sequence will not result in any significant structural damage to the 72-B Cask. Nearly all permanent damage occurs in the external impact limiters as desired. Minor amounts of damage can occur to cask components as follows:

In the 30-foot free drop event, a conservatively maximum bounding lead slump of 0.513 inch was estimated, as detailed in Section 2.7.1.1(9) (page 2-217). However, as demonstrated in testing of the NuPac 125-B Cask, no measurable lead slump would actually be expected to occur in the 72-B Cask as a result of flat end drop. For the 40-inch drop on a 6-inch diameter puncture bar, occurring on the side of the cask at midlength, localized cask damage can occur at the impact point. However, overall bending response of the cask remains elastic. Additionally, the outer cask outer shell will not be perforated, and no melting of the lead shielding would occur in the ensuing accident fire event.

The localized puncture damage would occur in the form of a reduction in lead thickness adjacent to the point of impact of the puncture bar. Pin punch results from the NuPac 125-B quarter-scale drop tests were analyzed to provide a conservative estimate of similar damage which could be expected for the 72-B Cask. It was determined that the 40-inch side drop on the puncture bar caused, at most, a 35% localized reduction in the thickness of the lead shielding on the 125-B Cask. This estimate is conservative for the 72-B Cask, because it is significantly lighter in weight than the 125-B, and puncture-induced deformations would be expected to be less.

As documented in Section 2.7.2, puncture on the top end of the cask can result in a slight, permanent inward deformation of the outer cask lid. However, stress levels remain modest and the inward deformation is very small and has been shown to increase containment O-ring compression. As such, the lid end puncture event does not adversely affect containment integrity.

These permanent deformations are of little consequence for the 72-B Cask as they represent only minor changes in cask geometry. In particular, damage is not sufficient to compromise "leaktightness" of the inner vessel or the outer cask containment boundaries. Lead deformation is only of concern relative to shielding. The worst-case puncture damage is therefore addressed in the shielding evaluation in Section 5.0. For these reasons, the integrity of the cask is not considered to be compromised by the accident test sequence set forth in 10 CFR 71.

Finally, as detailed in Section 4.3, full lateral offset of the IV and OC lids, which might result from side drop or side puncture, will not compromise the containment seals' leaktight capability. This is because, as demonstrated in the referenced section, O-ring compression remains above the minimum 10% required value under worst-case tolerance stackup and lid offset.